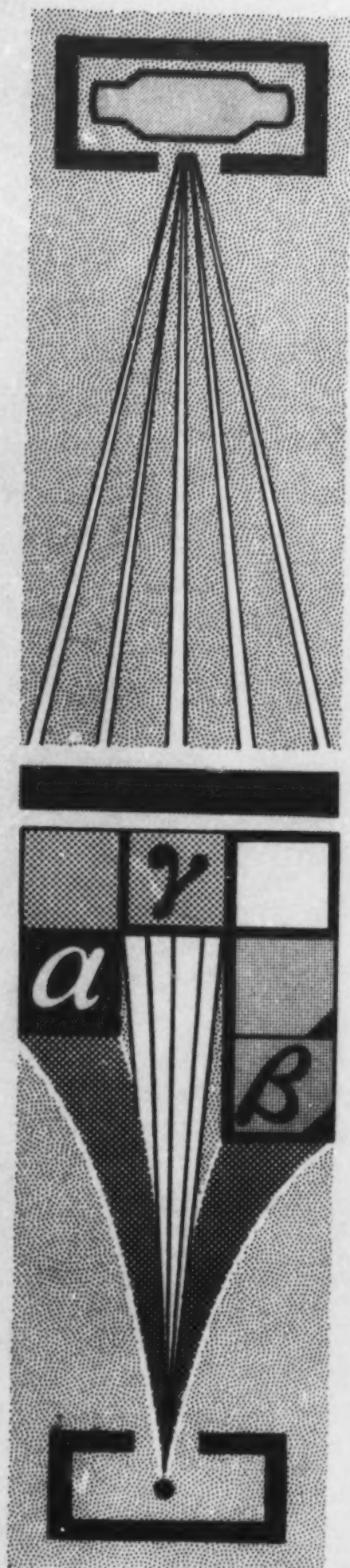


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A REVIEW and ANALYSIS of RADIUM INCIDENTS



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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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A REVIEW and ANALYSIS of RADIUM INCIDENTS

by

Earl W. Robinson, John C. Villforth, and Gary J. Wold

Radioactive Materials Section
Medical and Occupational Radiation Program



SEPTEMBER 1968

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Control Administration
National Center for Radiological Health
Rockville, Maryland 20852

MEDICAL AND OCCUPATIONAL RADIATION PROGRAM

Technical Reports

The following technical reports issued by the Medical and Occupational Radiation Program are available through the Office of Information, National Center for Radiological Health, Public Health Service, U.S. Department of Health, Education, and Welfare, Rockville, Maryland 20852:

PHS No. 1559	Physical Survey Manual Dental X-ray
PHS No. 1582	Radiation Protection Survey Report Manual
PHS No. 1633	KWIC Index to the Journal of the Health Physics Society (1958-1966)
PHS No. 1698	Radium and the Physician
PHS No. 1831	KWIC Index to the Journal of Nuclear Medicine (1960-1967)
PHS No. 999-RH-29	Tritium Contamination in Particle Accelerator Operation
PHS No. 999-RH-30	Reduction of Radiation Exposure in Nuclear Medicine
MORP 67-1	X-ray Emission from Shunt Regulator Tubes for Color Television Receivers
MORP 67-2	Radium Disposal Project
MORP 67-3	Radium Source Integrity Testing Progress Report
MORP 67-4	Design of Interlocked Radium Shipping Container
MORP 67-5	A Summary Report on X-ray Diffraction Equipment
MORP 67-6	Georgia Radium Management Project. . . Phase II
MORP 67-7	Decontamination Study of a Family Dwelling Formerly Used for Radium Processing (Preliminary Copy)
MORP 68-1	A Collection of Radium Leak Test Articles
MORP 68-2	Recommendations for the Safe Operation of Particle Accelerators
MORP 68-3	A System for the Registration of Radiation Sources
MORP 68-4	Medical Surpak Summary Report
MORP 68-5	The Use of Radium in Consumer Products (In preparation)
MORP 68-6	Preliminary Results of 5263 X-ray Protection Surveys of Facilities with Medical X-ray Equipment (1962-1967)
MORP 68-7	A Review and Analysis of Radium Incidents
MORP 68-8	Dental X-ray Teaching and Training Replica
MORP 68-9	Development and Evaluation of an Automatic Collimator for Medical Diagnostic X-ray Machines
MORP 68-10	Survey of the Use of Radionuclides in Medicine: Preliminary Report

FOREWORD

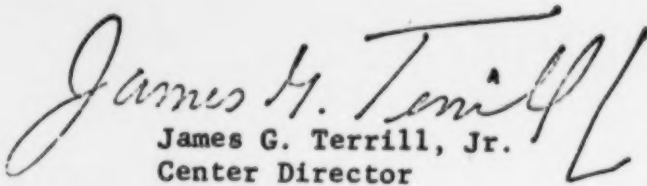
The National Center for Radiological Health conducts a national program for the prevention and control of radiological hazards to public health through (1) surveillance activities, (2) research and development programs, (3) technical assistance to governmental and other organizations, (4) technical training programs, (5) development of criteria and codes, (6) administration of grants, (7) consultation on international programs, and (8) public information and education activities.

The Medical and Occupational Radiation Program is the component of the Center which deals with reduction of unnecessary radiation exposure of patients, workers, and others incidentally exposed by the use of X-rays, radioactive materials, radiopharmaceuticals, and particle accelerators.

The Center publishes its findings in Radiological Health Data and Reports (a monthly publication), the Environmental Health Series, Public Health Service numbered reports, appropriate scientific journals, and Program and Branch technical reports.

The technical reports of the Medical and Occupational Radiation Program (MORP) allow comprehensive and rapid reporting of the results of inhouse and contractor projects. The reports are distributed to State and local radiological health program personnel, Center technical staff, Center advisory committee members, University radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are included in the collections of the Library of Congress and the Clearinghouse for Federal Scientific and Technical Information.

I encourage the readers of these reports to inform the Center of any omissions or errors. Your additional comments or requests for further information are also solicited.


James G. Terrill, Jr.
Center Director

PREFACE

In 1963 the National Center for Radiological Health (then the Division of Radiological Health) began to collect and analyze reports of radium incidents. This document presents an analysis of the 396 radium incidents which have come to our attention through December 1967. The more common causes of radium incidents are discussed and appropriate preventive measures are suggested. Thus, this document should be of special interest to Federal, State, and local radiological health personnel.

The success of the Center's continuing efforts in this area will depend, in large degree, on the responsiveness of health agencies in providing the Center with adequately-documented radium incident reports. These agencies have been most cooperative in the past, and we look forward to their continued cooperation, since they will be the primary beneficiaries of our efforts.

John C. Villforth
Chief, Medical and Occupational
Radiation Program

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INTRODUCTION

Incidents involving radium have occurred since the earliest days of radium usage. These have included losses, thefts, contamination from ruptured sources and other causes, and overexposures. The total number and severity of these occurrences cannot be determined since, in the past, there has been little professional concern and no governmental requirement for the reporting of these incidents. However, the development of State and Federal radiological health programs has produced an increased awareness of the need to control radium and has made it possible to conduct a systematic study of radium incidents.

THE NCRH RADIUM INCIDENT PROGRAM

Since 1962, the National Center for Radiological Health (NCRH) has collected, analysed, and disseminated radium incident information, in order to determine the extent and causes of radium incidents and to devise preventive measures. For our purposes we have defined an incident as any loss, theft, contamination event, or overexposure. Reports of both past and current incidents are being collected from a variety of sources. State health agencies and a newspaper clipping service have supplied most of the current data; reports of earlier incidents were collected from the literature and from persons associated with the use and production of radium (1-3). As of January 1, 1968, information on 396 incidents had been collected.

Automatic data processing has been used in processing and analyzing the information collected. Incident reports are abstracted and coded by type of incident, type of facility, etc. This information is punched on ADP cards and printed incident listings are then produced. These may be ordered in any suitable manner, *e.g.*, by date of incident. A system which will allow a more detailed analysis of the available data is currently being developed.

The NCRH periodically publishes summaries of radium incident reports. These summaries are distributed to State and Federal radiological health personnel for their information and also to encourage them to report such incidents to the NCRH.

FINDINGS

Type and Number of Incidents

Table 1 is a summary of the number and types of incident reports which have been collected. The incidents are grouped in five categories: loss, theft, contamination, overexposure, and miscellaneous.

Sixty-six percent of the reported radium incidents involve losses, virtually all from medical facilities. It is likely that the high cost of radium and the threat of serious radiation injury prompted many users

to seek assistance in recovery, thus leading to publication of the incident. Because of public interest, news media give wide coverage to these searches.

The contamination incidents recorded have resulted from ruptures or leaks in sealed sources, the processing and refining of radium, the operation of radon generators, and the use of luminous compounds containing radium.

The overexposure incidents noted in table 1 have occurred within the last few years. Documented exposures to radium in excess of current limits have rarely been reported. Such exposures must have occurred frequently in the past but could not be documented, since reliable personnel radiation dosimeters have not been commercially available until comparatively recent times. Even today many individuals occupationally exposed to radium do not use personnel dosimeters, especially in those States which do not require that they be used (4,5). Furthermore, many States do not require radium users to report overexposures.

The miscellaneous category includes structural separations of sources during therapy, equipment failures, and instances in which sources were found unexpectedly.

Table 1. Radium incident distribution, by type of incident and type of source

Type of Incident	Type of source				Total
	Medical		Nonmedical		
	Encapsulated	Non-encapsulated	Encapsulated	Non-encapsulated	
Loss	243	-	18	-	261
Theft	14	-	9	2	25
Contamination	52	4	9	11	76
Overexposure	5	-	2	-	7
Miscellaneous	12	1	6	8	27
Total	326	5	44	21	396

Medical Losses

Figure 1 shows the medical radium use cycle and indicates the percentage of losses which occurred in each phase of the cycle. Only 149 of 261 losses could be used in deriving these percentages, since the point of loss in the use cycle was not known in the remaining losses. An examination of figure 1 reveals underlying causes of radium losses, indicating where preventive measures are needed.

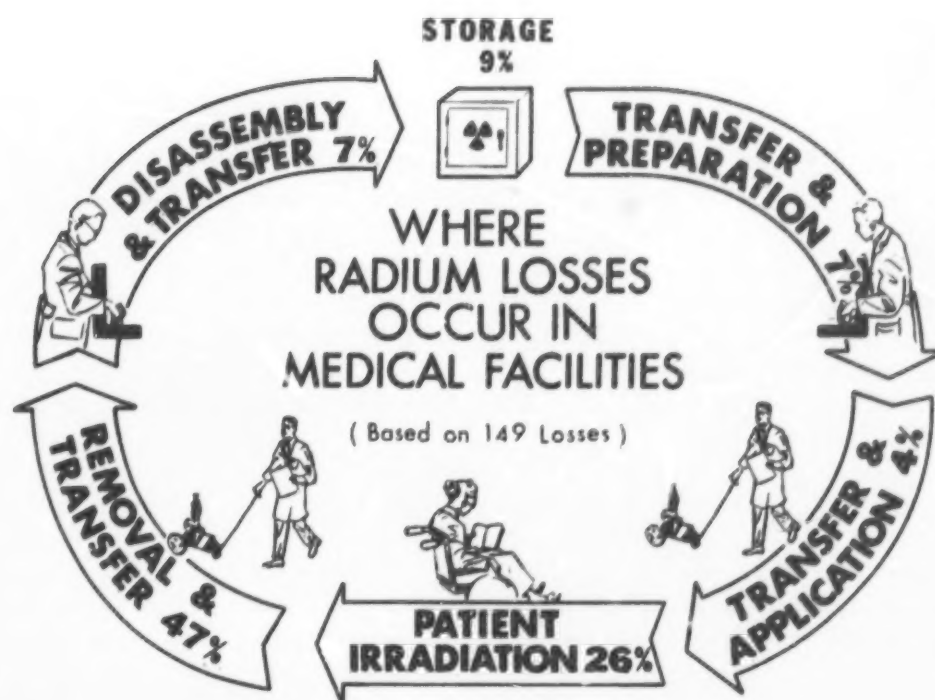


FIGURE 1

Nine percent of the losses occurred while the radium was in storage. Sources have been discarded on several occasions because the cabinet or container in which they were stored was not properly secured or identified. For example, 50 milligrams of radium stored in an unmarked lead container were recently lost from the basement of a medical arts building. A janitor removed the sources and, thinking they were of no value, threw them into the trash. Nearly a month passed before the loss was discovered. After an extensive search, the sources were recovered from the city landfill. This incident and many others strongly suggest the need for more frequent inventories, as well as for proper security and identification of containers.

Figure 1 shows that 7 percent of the losses occurred in the first operational phase of the cycle (Transfer and Preparation). These losses occurred during threading of the needles or assembly of the applicators. The sources were generally lost because they slipped out of the handling forceps or were accidentally brushed off the worktable. These sources could easily have been located if suitable survey instruments had been available. The losses might have been prevented by good housekeeping, adequate equipment and lighting, and proper design and organization of the working area.

Only 4 percent of the losses occurred during transfer of the radium from the preparation area, before its application to the patient, or during application. These losses were usually the result of carelessness or inadequate working procedures.

During patient irradiation, a marked increase in the number of losses (26 percent) was observed. Most of these losses were the result of (1) the patient's premeditated removal and discard of the radium, (2) the accidental discharge of radium during elimination of body wastes, (3) the patient's violation of instructions by leaving the treatment room, or (4) laxity in allowing a patient undergoing radium treatment to leave the hospital or clinic. In many cases the loss resulted from the patient's lack of understanding of the treatment procedure and from the lack of close supervision during treatment.

Forty-seven percent of the radium losses occurred during removal of the radium application from the patient or its transfer to the disassembly area. These losses resulted primarily from either of two sets of circumstances, both involving the large quantity of gauze packing or bandages in which the radium is generally entangled when it is removed from the patient. In the first case, the dressings containing the radium sources were removed and laid aside with no attempt being made to properly segregate and identify the sources. The bandages, still containing the radium, were later disposed of as trash. This type of incident could be prevented by monitoring all dressings and used bandages for radium sources or by accounting for all sources before discarding the dressings. In the second situation, the physician who treated the patient delegated the task of removing the radium sources to another physician, intern, or nurse. Because of inadequate instructions, part of all of the radium was again discarded with the dressings. One way to prevent this type of incident is to require that a diagram showing the number and arrangement of the radium sources accompany the patient's chart. When the task of removing the radium is delegated to another, the physician should also provide written instructions.

Seven percent of the losses occurred during the last phase of the cycle, disassembly of the applicators and transfer of the radium back to storage. Most of these losses occurred when disposable rubber and plastic appliances containing part or all the radium were inadvertently discarded because of inadequate instructions regarding the number and arrangement of the sources.

Recovery of Lost or Stolen Radium

The success in recovering lost or stolen radium sources is shown in table 2. Recovery attempts were completely or partially successful in only 50-70 percent of all losses and thefts. Complete recovery was more frequent for radium lost from medical facilities than for radium which was stolen, lost from nonmedical facilities, or lost during commercial transport. It might be expected that the recovery of stolen radium or radium

lost during commercial transport would be more difficult than recovering radium lost from a medical facility. In the case of stolen radium the thief must usually be apprehended before the radium can be recovered. For transportation losses the radium may have been lost anywhere along its route, which may extend across several States.

The table shows "No recovery" in a significant percentage of losses. Most of these unrecovered sources probably lie buried in municipal landfills and dumps where their potential hazard will exist for thousands of years.

Table 2. Recovery of lost or stolen radium

Type of loss	Recovery		No recovery	Total
	Complete	Partial		
Loss from medical facility	162 (68%)	8 (3%)	70 (29%)	240 (100%)
Loss from nonmedical facility	9 (53%)	0 -	8 (47%)	17 (100%)
Theft	11 (44%)	4 (16%)	10 (40%)	25 (100%)
Loss during commercial transport	1 (25%)	1 (25%)	2 (50%)	4 (100%)
Total	183 (64%)	13 (5%)	90 (31%)	286 (100%)

Table 3 shows where radium sources lost from medical facilities have been recovered. It suggests where one might begin looking for lost radium in the absence of more detailed information. The high percentage of recoveries from the trash system (54 percent) supports the hypothesis that most lost radium sources were discarded in used bandages during the removal and transfer activity. The category of "Other" in table 3 includes the laundry system, facility grounds, bed linens, and other less likely places.

Table 3. Recovery site of radium lost from medical facilities

Location	Number of incidents	Percent of incidents
Trash system	92	54
Sewage system	18	11
Floor of facility	18	11
Other	41	24
Unknown	1	-
Total	170	100

Contamination Incidents

Contamination incidents were also examined in detail because of their number and hazard. Table 4 provides data related to the occurrence of known, sudden rupture of sealed radium sources.

Table 4. Causes of radium source rupture

Cause of rupture	Number of ruptured sources	Type of encapsulation		
		Glass	Metal	Other
Internal Pressure				
Spontaneous	5 (11%)	4	1	0
Heat induced	2 (4%)	0	2	0
External Force				
Crushed	5 (11%)	5	0	0
Eyelet or tip broken off or pulled out	16 (35%)	0	16	0
Drilled or cut	6 (13%)	0	6	0
Other	5 (11%)	1	4	0
Other cause	1 (2%)	0	0	1
Unknown cause	6 (13%)	2	4	0
Total	46 (100%)	12	33	1

Twenty-six percent of the ruptured sealed sources were glass encapsulated. Although glass is no longer used to encapsulate radium sources, it was commonly used in the early days of radium therapy. Glass encapsulated sources are much more subject to breakage than steel or platinum-irridium encapsulated sources. Some of the glass encapsulated sources apparently exploded spontaneously, probably as a result of internal pressure buildup caused by the breakdown of water of crystallization of the radium salts. Radium salts, used to produce the earlier sources, were not always adequately dried. The interaction of radiation with the water of crystallization formed hydrogen and oxygen gas. The increased internal pressure then caused the source to rupture.

The largest number of ruptured sources (35 percent) resulted from the eyelet or tip of the source being accidentally broken or pulled out. Generally, breakage occurred when a radium safe drawer was closed on a source which was not properly seated in the drawer. Occasionally a friction fit eyelet plug was pulled out of the source during handling. Almost all such occurrences were the result of carelessness. Thirteen percent of all source ruptures were caused by either inadvertent or intentional cutting or drilling of the source. In one case, a technician cut

off part of the radium source in a level gage to reduce its activity. In other cases, sources have been cut or drilled during attempts to remove a "frozen" plug from the lead storage container.

Contamination incidents not involving known, sudden, sealed source rupture are shown in table 5. These incidents generally were the result of gradual accumulation of contamination from leaking sources or careless handling of unsealed radium. They were usually discovered by State health agencies. Occasionally a State or Federal agency became directly involved in lengthy and costly decontamination of a facility when the responsible individuals had vacated the facility, were deceased, or were not willing or financially able to decontaminate the facility.

Table 5. Contamination incidents not involving known, sudden, sealed source rupture

Type of contamination	Number of incidents
Massive contamination after long-term accumulation	11
Limited contamination	
Leaking sources	12
Industrial dial painting	2
Spill or careless use of radon pump	5
Total	30

Chronological Incident Distribution

Table 6 shows a chronological distribution of the reported incidents. The data show a nearly continuous increase in the number of incidents. The large increase since 1961 is undoubtedly a reflection of the growing involvement of State governments in the control of radium and the consequently greater likelihood that incidents will be reported. The increases from 1911 to 1950 may reflect the growth in the use of radium in medical therapy. The number of incidents reported to the NCRH have been essentially constant for the last four years. However, since not all incidents are reported to the NCRH, it is impossible to determine the trend of the true incident rate.

The distribution of incidents by type has changed over the years. The recent increases noted in the miscellaneous category support the above contention that a larger proportion of the incidents which occur are now being reported to State health agencies, since most of the type of occurrences in this

class, *e.g.*, an unexpected find of a radioactive source or object, would not normally have been publicized in the past. Another probable reason for the increase in the miscellaneous category is the growing public awareness of radiation hazards.

Table 6. Chronological distribution of radium incidents by type

Date of incident	Type of incident					Total
	Loss	Theft	Contamination	Over-exposure	Misc.	
Unknown	33	2	5	-	-	40
Before 1911	-	-	2	-	-	2
1911-1920	9	-	1	-	-	10
1921-1930	16	-	1	-	1	18
1931-1940	33	5	3	-	1	42
1941-1950	58	6	20	1	1	86
1951-1960	41	5	19	-	4	69
1961-1967	71	6	26	6	20	129
Total	261	24	77	7	27	396
1961	3	-	3	-	2	8
1962	8	-	1	-	-	9
1963	4	2	4	-	3	13
1964	17	-	6	3	2	28
1965	13	3	4	2	1	23
1966	14	-	5	-	6	25
1967	12	1	3	1	6	23

RECOMMENDATIONS

The adoption of the following recommendations by facilities which use radium should help to prevent or reduce the occurrence of radium incidents. These recommendations are based on the NCRH radium incident study.

1. Each facility should adopt adequate accountability procedures. Although accountability procedures may vary according to the facility, all procedures should incorporate the following essential features:
 - (a) Control of the issue and receipt of all radium sources should be the responsibility of one person (the source custodian). The source custodian should maintain a permanent record showing the (1) quantity, type, and activity of radium sources issued, (2) type and loading

of applicators used, if any, (3) date of issue, (4) person who initially received and those who subsequently received the radium (with signatures), (5) expected date of return, (6) actual quantity of radium used, (7) actual date of return, (8) amount of radium returned, and (9) certification by the source custodian as to the accuracy of the record. A copy of this record should be transmitted with the radium. A suggested radium issue and receipt form for medical facilities is shown in figure 2.

- (b) The source custodian should periodically inventory the radium stock. The inventory frequency should be directly related to the frequency of usage.
 - (c) Radium sources should be secured against unauthorized removal and access to the sources should be strictly controlled.
2. In medical facilities, appropriate procedures should be adopted to prevent loss of radium during patient irradiation and upon removal of the sources. The following are some of the actions which should be taken:
- (a) In addition to the form described in 1(a) above, a chart or form showing the quantity and location of radium sources used on or in the patient should be prepared. If the radium is to be removed by anyone other than the attending physician, written removal instructions should be provided. All of this material should be placed with the patient's bed chart.
 - (b) During the treatment period, nursing attendants should check the patient frequently for evidence of dislodging or removal of the sources.
 - (c) If at all possible, patients undergoing treatment with radium should be kept in a private or semiprivate room. They should not be allowed to leave the room during treatment unless directly supervised.
 - (d) When treatment involves sources that may be dislodged, patients should be required to use a bedpan to eliminate body wastes and should not be allowed to use regular toilet facilities. Standing instructions should be given to nursing attendants to check the patient's bedpan for dislodged radium sources (with a radiation detection instrument) before discarding wastes. All linen and trash should be monitored for the presence of radium before removal from the patient's room.

ISSUE AND RECEIPT OF RADIUM

NAME OF PATIENT _____ No. _____

HOSPITAL _____ Date of Treatment _____

A. RADIUM ORDER

No. and type of needles or tubes	Type of applicator and/or identification	Mgh.

The above radium was removed from safe by _____ Date _____

Radium made up by _____ Checked by _____

Received by _____ Date _____ (Any discrepancy must be reported at once)

B. UNUSED RADIUM

(To be returned without delay to radium dept.)

The above amount checked and returned to safe by _____ Date _____

C. RADIUM ACTUALLY USED

Number and type of needles or tubes	Location on or in patient (draw diagram if needed)

To remain inserted for _____ hours, and be removed on _____ at _____ A.M.
P.M.

D. RETURN OF RADIUM

Amount returned _____

Received in Division of Radiotherapy by _____ Date _____

Checked and returned to safe by _____ Date _____

NOTE: Sections B & C to be completed by doctor inserting radium.

FIGURE 2

- (e) When radium sources or applicators are removed from the patient, they should be carefully counted to assure complete removal. The radium issue and receipt form mentioned in 1(a) above and the chart or form and written instructions mentioned in 2(a) should be used for this purpose. All dressings, bandages, and source packing should be retained until monitored for the presence of radium with a suitable radiation detection instrument or until all sources are accounted for and their return is certified by the source custodian.
 - (f) Radium sources which are removed from the patient should be placed immediately in a properly labeled and shielded container which should be taken as soon as possible to the radium storage area and turned over to the source custodian for disassembly, cleaning, counting and return to storage. In the event that the radium is removed at a time other than normal duty hours, there should be a trained individual on duty who is authorized to act as source custodian.
3. The radium storage safe and storage area should be designed to minimize losses, facilitate source handling, and minimize personnel radiation exposure. The radium storage safe or container should provide for ready removal and return of radium sources. There should be no possibility that a source will be damaged or ruptured while opening or closing the safe or container. Stored sources should be separated and segregated by type so that they will be readily identifiable and the inventory status can be easily determined.
 4. All radium preparation and disassembly work surfaces should have raised edges or sides to prevent sources or applicators from rolling off. All joints and cracks in radium preparation and disassembly areas should be covered to prevent small sources from becoming lodged in them.
 5. Rules designed to prevent radium incidents and promote radiation safety should be developed and posted at appropriate locations in each facility using radium. Such rules should include procedures to be followed in the event of any incident involving radium. These emergency procedures should include (1) monitoring of all wastes leaving the facility after discovery of a radium loss, (2) procedures for minimizing the spread of contamination in the event of a source spill or rupture, (3) the telephone numbers of the facility radiation safety officer and the appropriate State radiological health agency.

SUMMARY AND CONCLUSIONS

The National Center for Radiological Health has collected and analyzed 396 radium incident reports as of January 1, 1968. Most of the incidents involved the loss of sealed radium sources from medical facilities, primarily during irradiation of the patient or during removal of the radium from the patient.

Most of these occurrences could have been prevented by caution and common sense in combination with good accountability procedures. Adequate accountability procedures also increase the chances of locating a radium source once it is lost, since the loss would be noticed sooner and the probable place and time of loss more readily identified.

Complete recovery was effected in 64 percent of all losses and thefts, partial recovery in 5 percent and no recovery in 31 percent. Fifty-four percent of the recoveries of radium lost from medical facilities occurred in trash systems. In general, these recoveries were made in municipal dumps or sanitary landfills.

Sixty-one percent of all reported contamination incidents were caused by the sudden rupture of sealed radium sources. The remainder were caused by leaking sources or careless use of unsealed radium. Most source ruptures resulted from careless handling or irrational acts.

Our data indicate an almost continuous increase in the yearly number of incidents. This may be the result of the increasing use of radium up to the 1950's and the increased likelihood of incidents being reported to health agencies within the last few years.

Each radium incident represents an actual or potential health hazard. By collecting and analyzing radium incident reports, the NCRH has been able to indicate the scope and magnitude of these incidents and suggest means for their prevention. Our continuing collection and analysis of such reports should serve to better define the problem and to evaluate the success of State and Federal radiological health programs in reducing radium incidents.

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Wold; Sept. 1968; MORP 68-7; RMS, MORP, NCRH, DHEW.

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(over)

KEY WORDS:

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Sudden source rupture, which resulted primarily from careless handling of sources, accounted for 61 percent of all contamination incidents.

A chronological listing of radium incident reports indicates a nearly continuous increase in the frequency of incidents. This may reflect both the increasing use of radium up to the 1950's and the increased likelihood of incidents being reported to health agencies within the last few years.

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occurred primarily during irradiation of the patient or during removal of the radium from the patient. Fifty-four percent of the recoveries of radium lost from medical facilities occurred in trash systems. No recovery was made in 31 percent of all radium losses and thefts.

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